LARGE CLASS 1.3 ROCKET MOTOR DETONATION CHARACTER

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ABSTRACT

Large explosive class 1.3 solid propellant rocket motors utilizing polybutadiene binder, aluminum fuel, and ammonium perchlorate oxidizer are typically considered explosively "safe". That is, the required stimulus is so large that motor detonation is extremely unlikely, even when donored by a sizeable high explosive charge. Two large ground cratering events have occurred during recent years in motor destruct operations. Recently, a 10,000 kilogram grain containing 90 percent combined aluminum and ammonium perchlorate solids was subjected to a 25 kilogram C4 donor. Discussion of the nature of these events and the large test and how observed results affect our outlook on large motor hazards will be presented.

INTRODUCTION

Hydrocarbon binder/aluminum (Al)/ammonium perchlorate (AP) solid propellants having burn rates near one centimeter per second have been usually considered to have almost negligible explosive character. This had come in part by analogy with the 84% total solids (68% AP and 16% Al) Minute Man (MM) I carboxy terminated polybutadiene-acrylonitrile (PBAN) propellant that was shown to have a critical diameter between 1.676 and 1.829 meters (66 and 72 inches) (1). However, with the French publication in 1988 (2) where a slow burning hydroxy terminated polybutadiene (HTPB) propellant containing 90% total solids (70% AP and 20% Al) was reported as having a critical diameter near 85 mm (3.35 inches), our concept of detonability of our "safe" propellants having total solids loadings above 84% may have to be changed considerably.

A cratering event was observed during destruction with C4 explosive charges of a SRAM (short range attack missile) propulsion unit at Hill AFB in 1989. This was considered somewhat unusual but didn't raise any great concerns since the propellant has its burn rate catalyzed by a mixture of n-butylferrocene and di-n-butylferrocene. Due to this burn rate catalyst system SRAM propellant has been known to produce fires by friction and impact events encountered with the SRAM propellant since its introduction into use.

During C4 donored destruction of a MM II, stage 3 motor in 1990 at Hill AFB a large cratering event occurred. This was the first apparently full energetic yield explosion ever observed with the MM II, stage 3 motor. This motor contains

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about 7300 pounds of an 88% total solids (73% AP and 15% Al) carboxy terminated polybutadiene (CTPB)/aluminum/AP uncatlyzed solid propellant. Since the motor is 1.32 meters (52 inches) in outer diameter, the propellant critical diameter must be substantially smaller than for the 84% solids PBAN propellant tested during the 1960s.

During the 1960s, several launch failures with explosive class 1.3 boosters exploded violently when impacting the earth or ocean according to Lou Ullian of the Patrick AFB safety group (3). Thus, explosive class 1.3 propellants producing a lack of detonation at zero cards in the large card gap test have exhibited significant explosive character in large rocket motors. The lack of atmospheric overpressure gauges has not allowed estimation of explosive yield in the observed US explosive events by class 1.3 propellants. Craters produced by the SRAM and MM motor violent explosions were large enough to cause belief that complete energetic yields had been obtained.

Presently, the USAF has a lack of quantitative knowledge as to the relative explosive and fire initiatability of our safer propellants that are used in larger booster motors. Although it is generally believed that large motors are more vulnerable at lower impact velocities than for small motors, the change in explosive character with increasing motor size has not been experimently determined. Poorly quantified events with large critical diameter explosives such as, safer solid propellants, has indicated that their explosive characteristics might be quite different from high explosives. Later, a short discussion will cover the rather strange (to me) behavior of a 90% total solids propellant during an explosive process. Explosive potentials of large solid boosters that weigh about 250,000 kilograms or more (Titan and Space Shuttle) have been a growing concern of range safety officiers during launches. Study of large motor explosive traits and how to increase their explosive resistance has been suggested by several people.

Figure 1 exhibits two plots involving critical diameter of solid propellants. The first plot involves my concept of propellant critical diameters versus large card gap test results. The range of critical diameters, 0.25 to 2500 millimeters (roughly, 0.01 to 100 inches), includes critical diameters for all rocket propellants used by the US military services and NASA. Seventy cards in the card gap test divides the explosive class 1.1 and 1.3 solid propellants. Since many propellants have critical diameters in steel pipe above the 37 mm (1.44 inches) inside diameter employed in the large card gap test, our generally recognized as "explosively safe" solid propellants provide only negative results at zero cards. Thus, the card gap test doesn't provide a relative measure of explosive sensitivity for zero card propellants. Without quantitative evidence in hand it is relatively easy for us to imagine, incorrectly, that all of these propellants are of about equal explosive insensitivity.

In the second plot of Figure 1 the safe propellant critical diameters are expanded versus solid propellant solids loadings for hydrocarbon binder/aluminum/AP propellants. Only two data points come from experimental data. The first data point is the roughly 1700 to 1800 mm (about 70 inches) critical diameter at 84% total solids for the stage 1, Minute Man I missile propellant. The second data point was obtained from French workers referred to in the footnote. They determined an 83 mm (3.27 inches) critical diameter for a 90% total solids HTPB propellant. By interpolating between the two experimental points, critical diameters can be roughly estimated for 86 and 88 weight percent solids loaded solid propellants of the HTPB, CTPB, PBAN, etc. types. Considerable variation in critical diameters at a particular solids loading for propellants would be expected as the AP particle sizes, AP content, burn catalyst contents, and other formulation parameters were varied. Critcal diameters cover a considerable range for the "safe" solid propellants. We are just beginning to recognize that explosive characteristics associated with very large rocket motors might be a substantial range safety concern. A large portion of the concern is due to the fact that relatively low impact velocities may be capable of stimulating detonations of the largest rocket motors in launch failure fallbacks near the launch pad.

Figure 2 exhibits an artistic attempt at illustrating how threshold fire and violent explosion stimulating impacts might decrease as the quantity of propellant increases. Some very limited data has been generated for explosive class 1.1 propellant samples of less than 10 kilogram weight that indicates a roughly linear logarithmic impact velocity-propellant weight relationship. However, no systematic study of large critical diameter propellant explosive vulnerability as a function of sample size has been conducted. Several serious fire incidents have been experienced with HTPB propellants indicating that a relationship between fire threshold impact velocities and sample size could also be useful. At the present time no data is available to show how fire initiation impact velocities vary with impacting sample weight.

EXPERIMENTAL

As a means of getting limited information on relative explosive nature for a high solids HTPB propellant, a simple experiment was planned at the Edwards AFB section of the Phillips Laboratory early this year. See Figure 3. The sample was a 10,000 kilogram (22,622 lbs) grain that is normally used in our Super HIPPO nozzle survivability test motor. Our cylindrical propellant grain was 2.13 meters (7.0 feet) in outer diameter, 2.24 meters (7.3 feet) in length, and contained a 0.61 meter (2 feet) center perforation. This resulted in a web thickness of 0.76 meter (2.5 feet). Propellant making up the Super HIPPO grain was a 90% total solids HTPB formulation containing 21% aluminum and 69% AP that had an uncatalyzed, relatively slow burn rate of about 1.0 centimeters (0.40 inches) per second at 6.9 megapascals (one thousand psi). A right circular cone of C4 donor explosive was placed sitting at mid-web on one side of the vertically oriented grain sitting on a dry soil surface. The cone had a 0.30 meter (one foot) maximum outer diameter by 0.60 meter (2 feet) in height. Total C4 explosive donor weight was near 24.5 kilograms (54 pounds). Instrumentation was a few Bikini overpressure gauges (variable size paper disk gauges) and a pair of 30 frame per second color video cameras.

The Super HIPPO grain explosive test was based on a few simple concepts: (1) The propellant was quite similar to that used by the French that yielded an 83 mm critical diameter, 69% AP and 21% Al versus 70% AP and 20% Al. Thus, a similar critical diameter might be expected. (2) A 0.30 meter diameter C4 explosive donor was used so that lack of violent explosion would be reassuring that the propellant was roughly as explosively safe as initially thought or that we would consider further study if the propellant produced a violent explosion. (3) If the donor exceeded the propellant critical diameter, all of the propellant should detonate. (4) If critical diameter was not exceeded, air shock pressures would be relatively weak. (5) At less than critical diameter a violent explosive event initiated by the donor should die before the bottom end of the grain. (6) With a dying supersonic shock event in the propellant unconsumed solid propellant should be lying on the earth directly below the C4 donor.

When the C4 donor was set off by an exploding bridgewire initiator, an explosion considerably stronger than could be produced by the donor charge alone was observed. Large amounts of the propellant was not consumed in the process and an enormous number of burning and nonburning propellant fragments were thrown out of the reaction zone. Unconsumed propellant was not located in the crater although a very large number of unconsumed propellant pieces in sizes sometimes exceeding 10 kilograms (20 pounds) were observed on the ground out to distances beyond 0.75 kilometer (2500 feet) from the event. A large, clean, somewhat assymetric crater was produced in the soil about 1.2 meters (4 feet) in depth and 5 meters (16 feet) in diameter. An illustration of the approximate cross section of the crater is provided in Figure 4. By past experience on the same ground with large explosive charges the crater size seemed to indicate an explosive charge equivalent to roughly 700 kilograms (1500 pounds) of TNT. Observation of the sizes of torn paper circles in the Bikini overpressure gauges indicated a TNT equivalence somewhere between 450 and 2300 kilograms (1000 and 5000 lbs.

DISCUSSION/CONCLUSIONS

From the evidence produced by the C4 donored 90% solids HTPB propellant in the large grain several factors seemed to standout.
(1) The size of the overpressures and the substantial crater produced indicated that partial detonation or a partial full yield explosive event had occurred. (2) Further support for this view came from the crater that had no evidence of free propellant within it. If a detonative process had died before exiting the propellant grain bottom, some evidence of solid propellant being in the crater after the event should have been observed. If propellant had burned in the crater following the event aluminum oxide stains would have been present, and some amount of green glass formed by heating of our low temperature melting soil should have also been seen. No propellant fragments, burn stains, or green glass were present in the crater produced by the experimental event. From this it appeared that a detonation proceeded from the donor out the bottom of the Super HIPPO grain. (3) If a detonative type of process transited 2.13 meters (7 feet) through the propellant grain, the critical diameter had been exceeded. This indicated that the French report for the relatively small critical diameter of 90% solids HTPB solid propellant was correct. (4) Why wasn't the propellant completely consumed in a detonative process? After some thought, a plausible explanation seems to be that the directed supersonic shock transmitted by the C4 donor into the solid propellant could not turn fast enough or build up fast enough in lateral directions to involve greater amounts of energetic material. In Figure 5 is indicated the way such a shock might pass through the propellant. That is, a gradually widening conical section of material that would produce full energetic explosive yield while the remainder of the propellant would be thrown out in fragments. For me this was a new concept. That is, that large critical diameter explosives have a great reluctance for bending detonation waves once a directional shock process has been initiated.

I believe that further study of the explosive characteristics of "explosively safe" solid rocket propellants should be further studied. Funding to support study of the Super HIPPO propellant has not yet been obtained. However, limited support is being made available to conduct experimentation with 88% solids HTPB propellant. Such studies are sure to provide interesting information about reactive traits of large critical diameter explosives and to provide some new and needed qualitative and quantitative observations on the relative safety of workhorse solid propellants.

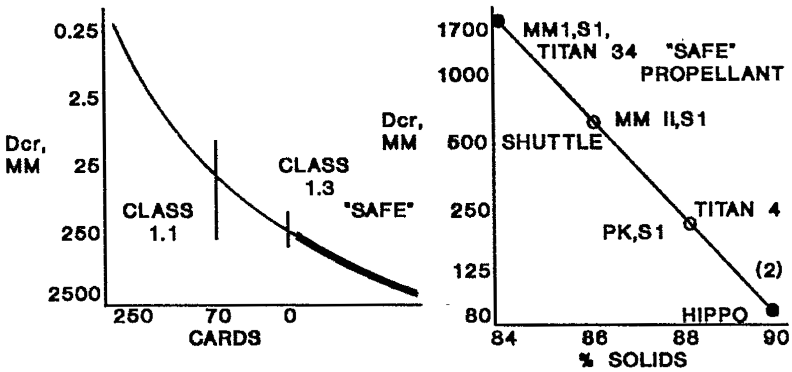
REFERENCES

1. Restricted source.

2. "Detonation Critical Diameter of Advanced Solid Propellants", J. Brunet - B. Salvetat, Joint International Symposium on Compatibility of Plastics, Pyrotechnics and Processing of Explosives, Propellants and Ingredients, New Orleans, 1988.

3. Lou Ullian, private communication.

FIGURES



(2) "DETONATION CRITICAL DIAMETER OF ADVANCED SOLID PROPELLANTS", J BRUNET - B SALVETAT, JOINT INTERN. SYMP. ON COMPATIBILITY OF PLASTICS, PYROTECHNICS AND PROCESSING OF EXPLOSIVES, PROPELLANT AND INGREDIENTS; NEW ORLEANS, 1988

Figure 1. Propellant Critical Diameter Versus Gap Sensitivity and Solids Loading

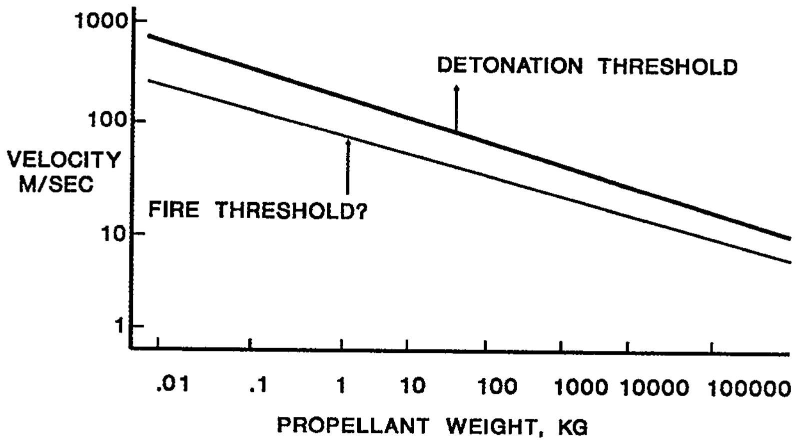


Figure 2. Explosive Threshold Velocities Versus Propellant Weight (Ignition Thresholds?)

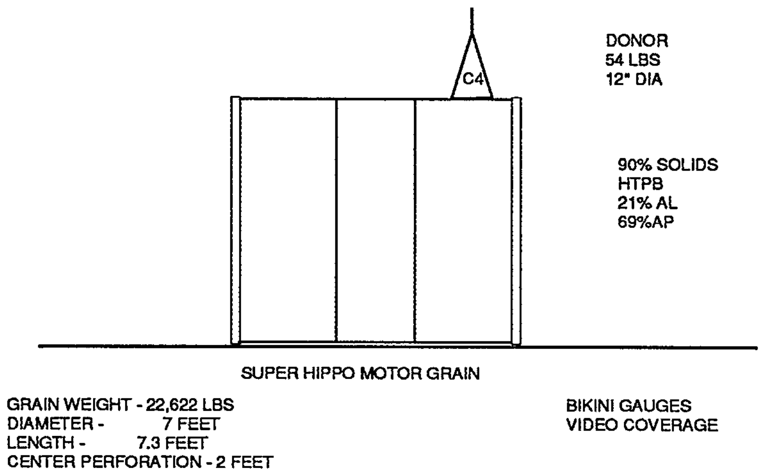


Figure 3. Super HIPPO Detonation Trial Configuration

- LARGE, CLEAN CRATER - 4 FT DEEP, 16 FT DIAMETER
- 20 LB + PROPELLANT CHUNKS TO 2500 FT
- CRATER SIZE INDICATED 1500 LB TNT EQUIVALENT
- BIKINI GAUGES INDICATED TNT EQUIVALENCE BETWEEN 1000 AND 5000 LBS

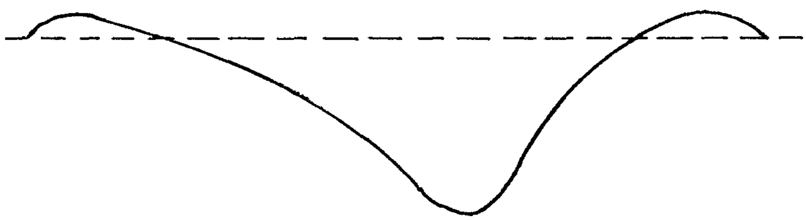


Figure 4. Super HIPPO Detonation Trial Results

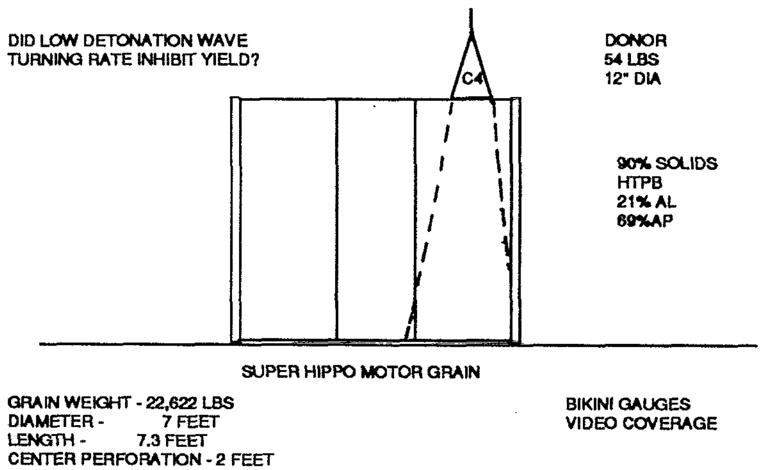


Figure 5. Super HIPPO Detonation Trial; Probable Shock Path Through Grain